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HYDROCYANIC ACID (HCN) AS A WAR GAS*

Conclusions

Whether or not hydrocyanic acid (HCN) is an effective war gas, likely to be used by the Axis, has been the subject of considerable debate. Authorities who believe its use probable base their opinion on the following considerations:

1. It is one of the strongest poisons known.

2. It is the only known war gas that has an instantaneous lethal effect if applied in sufficiently high concentrations. It is an invisible gas.

3. The instability of HCN, which was one of its disadvantages in the last war, is claimed to have been overcome by the addition of certain chemicals.

4. If applied properly, chiefly in larger units, it might be more effective than it was in the last war. For instance, larger caliber shells (over 75 mm.) might be effective in the field; large bombs (100 lbs. to 1,000 lbs.) might be effective against cities; mines, "booby traps," or hand grenades filled with HCN would be effective in enclosed spaces.

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Those who feel its use improbable base their opinion on the following considerations:

1. It is so extremely volatile that it was the least persistent of gases used in the last war, when it was

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* A joint MEW-OSS study.

actually championed only by the French. Attempts to mix it with heavier substances to increase its density were then rather unsuccessful, because the added substances (a) increased the dilution, (b) decreased its rate of evaporation, and (c) made the gas visible.

2. It is not lethal except in high concentrations which could not be attained under field conditions in the last war except at the point of impact of a gas shell. Concentrations up to 30 mg. per cubic meter of the systemic toxic HCN are harmless and can be breathed and eliminated by the body indefinitely, while similar concentrations of lung-injurant gases such as phosgene are highly lethal. The Germans say that practically no casualties were produced by HCN in the last war.

3. HCN is an inflammable substance, relatively unstable to shock, with a tendency to decompose on long storage; even its vapor is flammable and explosive, especially in high concentrations.

4. Modern gas mask filters absorb HCN except in excessively high concentrations. In the last war, because of the small volume of chemicals contained in the cannister, German masks were the poorest in this respect.

Our conclusion is that the use of HCN on a large scale by the Germans is quite unlikely in view of (1) the undesirable physical and chemical properties of the gas, and (2) their own experience facing ineffective French attacks with HCN in the last war.

If use

If satisfactory methods of applying high concentrations of HCN were developed, the gas might find limited use in this war. HCN filled in larger caliber artillery shells and aerial bombs might be a more effective chemical agent than it was in the last war. However, it would still be less efficient than phosgene or similar amounts of high explosives and incendiary bombs, which would cause material damage as well as casualties.

If used to supplement an attack with high explosives and incendiaries, HCN would be of psychological value and would force the enemy to wear masks, thereby reducing fighting efficiency. On the other hand, this could also be achieved by other gases, and on a still more effective scale by applying a non-flammable lung-injurant type of gas such as phosgene (or diphosgene in the case of the Germans) which has the following advantages over HCN that (1) it is less volatile, (2) it is more persistent, and (3) it has a greater cumulative toxic effect, especially in lower concentrations.

Manufacture

Hydrocyanic acid (HCN) has long been known as one of the strongest of all poisons. It is generally obtained by distilling a concentrated solution of sodium-(or potassium-) cyanide with dilute sulfuric acid and absorption of the resulting vapors in water. This is subsequently redistilled to obtain the anhydrous form used as a war gas. Neither raw materials nor manufacturing capacity would limit production of HCN if the European Axis decide to make it.1/ However, no reports have reached us that would indicate that the Axis is preparing HCN for large-scale use as a war gas.

Physical Properties

Pure hydrocyanic acid is a colorless liquid, approximately 0.7 as heavy as water. It boils at 26.5 degrees centigrade (79.7 degrees Fahrenheit), yielding a light vapor only 0.93 as heavy as air. Since the vapor is exceedingly volatile (873 mg. per liter at 20 degrees centigrade), it persists only a few minutes on the ground unless applied in huge quantities. Therefore, it was considered the least persistent gas used in the last war. It would, of course, be slightly more persistent in cold than in warm weather. To overcome the disadvantages (1) that it diffuses too rapidly, (2) that it is unstable to shock generally, (3) that it tends to decompose, sometimes with explosive force (but with complete loss of toxic effect), and (4) that it decomposes gradually in

water and corrodes metals when moisture is present, the French, who were the chief exponents of HCN in the last war, added various chemical agents (arsenic trichloride, tin tetrachloride, chloroform) in an effort to stabilize it and make it heavier.

World War I Use of HCN

Starting July 1916, the French used HCN in the following forms:

Covering Name	Chemical Substances
1. Forestite[2]	HCN
2. Manganite	HCN 46-50%, arsenic trichloride (AsCl3) 54-50%
3. Vincennite	HCN 50%, AsCl3 30%, tin tetrachloride (SnCl4) "Opacite" 15%, chloroform 5%.

Total French production of Vincennite during the last war amounted to 4,160 metric tons.[3] Most of this was filled in 75 mm. artillery shells. The various forms in which the French, and to a much lesser extent the Russians and British, applied HCN in the last war, are listed in Appendix 1.

The fact that the French applied HCN chiefly in the form of 75 mm. shells which contained only about 1 lb. of HCN which quickly volatilized made it impossible to place high concentrations except in the immediate area of shell bursts. Even in the Vincennite and Manganite mixtures, the volatility was so great that the gas mixed quickly with air and became so diluted that its strong toxic effect was lost. Addition of silver oxide to the German gas mask filters was claimed by them to have

effectively neutralized concentrations of HCN that were attained.

The French apparently also tried adding small amounts of HCN to chlorine in a few cloud gas attacks in an attempt to boost chlorine's lower toxicity.[4] Reference to an isolated case of aerial bombing against Metz in 1916 in which a Vincennite mixture was reportedly used is made in German literature,[5] but confirmation in French literature has not been found.

The French claimed good results for the use of HCN,[6] whereas the Germans have categorically stated that even with the addition of stabilizers and substances to make the gas heavier, the HCN used against them produced practically no casualties.[7]

The German attitude toward hydrocyanic acid as a war gas - at least in the last war - was best expressed in 1937 by Dr. F. Flury,[8] who conducted experiments on the toxicity of various gases during and after the war. He states: "A classical example for the difficulty of judgment and possibilities for error is supplied by the history of hydrocyanic acid. The French applied this extremely poisonous gas against our troops in amounts of allegedly 2,000 tons, and held fast to the end to this chemical warfare agent. It was not used at all by the Germans. Exact studies on the quantitative relationship between the effective gas concentrations and the time of exposure showed beforehand that it would be completely ineffective as a chemical warfare substance in the field. This prediction was also confirmed. No German soldier was

the victim of this gas."

Possible Use of HCN in World War II

An American source 9/ ascribes the apparent French failure with HCN to its application in the form of relatively small shells (mostly 75 mm.) and suggests that larger caliber HCN shells would be effective, especially if the chemical instability can be overcome with the addition of chemical agents, as developed since the last war. In 1935 a Russian authority 10/ listed HCN as one of the nine important chemical agents in future wars. HCN in the form of bombs dropped from high altitudes has also been mentioned 11/ as one of the gases, along with mustard and phosgene, which the Germans might use if they attacked RAF airdromes in a possible invasion attempt. On the other hand, German literature as late as 1939 definitely indicates that they did not consider HCN effective, and that they did not consider that any improvements which would overcome the World War I shortcomings of HCN had been found. 12/ This is partial, but of course by no means conclusive, evidence that the Germans did not contemplate using this type of gas.

In view of the apparent differences of opinion as to the effectiveness of this gas and as to the likelihood of the Axis using it, an attempt is made here to analyze its advantages and disadvantages in the light of foreign literature and foreign experience. From a qualitative point of view, HCN seems to have certain obvious merits. It is the only known gas which has an instantaneous lethal effect if applied in sufficiently high concentrations.

Aerochemical warfare may offer some new forms of application which are also examined. From a quantitative point of view, however, the application of HCN, even if stabilized, still presents great difficulties. The considerable differences in experimental data in this country and abroad on the toxicity and effectiveness of HCN as well as other war gases are also examined in the following section.

Toxicity of HCN

Because of its physiological effect, hydrocyanic acid is considered a systemic toxic agent. Death from paralysis of the central nervous system results when sufficiently high concentrations enter the blood stream to cause a general systemic poisoning. To evaluate the relative effectiveness of a systemic toxic of the type of HCN, it is helpful to compare it with the typical lethal lung-injurant, phosgene.

During the last war the Germans considered phosgene (and diphosgene, which breaks down into phosgene and is of about equal toxicity, although more persistent and easier to handle than phosgene) the most effective lethal gas. Its advantages over HCN are:

1. Phosgene is highly toxic in low concentrations, which were the only ones that could normally be obtained under actual combat conditions in the last war. For physical reasons, lethal concentrations of HCN were rarely attained in the field.

2. Phosgene's effect is cumulative, i.e. it is not

"digested" or eliminated by the body, and is independent of concentrations. Concentrations of HCN up to 30 milligrams per cubic meter of air can be breathed without ill-effect.

3. Phosgene is not so readily detectable by odor as HCN so that lethal amounts will sooner be breathed without being noticed. Symptoms of phosgene poisoning and death do not become apparent until some time has elapsed, which can at times also be a disadvantage for phosgene as compared with HCN.

4. Phosgene, and especially diphosgene, even though relatively non-persistent when compared with mustard gas, are at least more persistent than HCN.

HCN's chief advantage over phosgene - and an important one - is that if breathed in sufficiently high concentrations, its lethal effect is instantaneous, whereas that of phosgene is delayed. In high concentrations HCN appears to be more toxic than phosgene.

To evaluate the relative toxicity of chemical warfare agents during the last war, a so-called "lethal index" was set up for each gas, based on experimental data with animals. There is considerable variation in experimental data and in the interpretation of results, both in this country and abroad. The basis for computations accepted in this memorandum is contained in Appendix 2.

According to these calculations, the quantity of the lung-injurant <u>phosgene</u> which has to be breathed by humans to cause death is about 40 milligrams. This lethal

dose, at least according to Haber and Flury, is constant for phosgene and is essentially independent of time and concentration.

Because of the different physiological effect of the systemic toxic HCN, the results for this type of gas are more variable. The effect is partly reversible and no constant value for the lethal index of HCN can be given. This type of gas is almost instantaneously lethal if breathed in sufficiently high concentrations for a short time. On the other hand, in low concentrations - which would have a cumulative lethal effect in the case of phosgene - HCN is perfectly harmless. The quantity of HCN which thus has to be breathed for a lethal dose depends entirely on the concentration in which it occurs.

At high concentrations of say 3,000 milligrams per cubic meter of air- which heretofore could rarely be attained in the field - HCN may be said to be about twice as poisonous as phosgene. At this high concentration, as soon as about 20 milligrams have been breathed, death will occur. However, in the range of low concentrations up to 30 milligrams per cubic meter of air, a lethal dose of HCN would be unobtainable since a total quantity of about 300 to 350 milligrams could be eliminated or "digested" by the body during the course of a day. In terms of absolute quantities of HCN breathed, about 15 to 20 times the sudden lethal dose of HCN at high concentrations can thus be harmlessly thrown off by the

human system during the course of a day if the HCN is breathed in low concentrations under 30 milligrams of HCN per cubic meter.

Compared with phosgene, which is fatal as soon as about 40 milligrams have been breathed in an irreversible reaction, HCN is therefore much less effective in the lower concentrations ordinarily obtainable since 300 to 350 milligrams of HCN per day could be resorbed continuously without harm. In the last war, it was in the low concentrations of between 5 and 50 milligrams of phosgene per cubic meter of air that phosgene was at first lethally effective and later forced soldiers to wear masks.

Forms of Application and Relative Effectiveness of HCN

A. Aerial bombs. The fact that HCN vapor has an instantaneously lethal effect if suddenly applied in large quantities calls for consideration of how this might be attained. As already stated, it is not easy to produce large gas quantities in high concentration at the target in the form of HCN vapor.

A huge aerial bomb simply filled with liquid HCN would be ineffective unless means were provided so that it would evaporate quickly enough to yield HCN vapor of a sufficiently high concentration to be lethal. Even with the simultaneous release of smaller bombs, which would have the advantage of greater dispersion over the target area, only a fraction, say 10 to 20%, of the liquid would evaporate to gas suddenly enough to yield the necessary lethal concentration in a given area. For example, for a large bomb

of about 500 kg. HCN content - with a total bomb weight, including the filling, of about 1,000 kg. - the size of the effective target area would have to be less than 100 by 100 meters square, assuming a gas cloud layer 10 meters high. This is the maximum area (volume) in which an immediate evolution of gas would result in a concentration of 1000 milligrams per cubic meter of air, the minimum required to obtain a lethal effect in one or two minutes.

An aerial gas bomb filled with HCN as described above would have a highly effective competitor in the standard high explosive block buster bomb. The latter would cause considerable material damage as well as casualties within a target area the size delimited above. The advantage of gas over high explosives, i.e. that any gas developed from a bomb would remain longer on the target, and would also migrate to adjacent areas, would be partly counteracted by the proper use of gas masks. Furthermore, because of atmospheric conditions, dilution would quickly reduce the gas cloud's toxicity, especially in the case of HCN.

B. Artillery Shells. In the case of artillery shells, it has been suggested that HCN might be more effective than it was in the last war if a larger caliber (over 75mm.) would be used. However, only the amounts of HCN as used in smaller caliber shells would normally vaporize quickly enough to be effective, and would thus only touch small areas around the point of impact of a shell. Furthermore, experience in the last war showed that it took intense and protracted

artillery bombardments to cover an area with the lower concentrations in which phosgene was effective. It would accordingly require a much larger number of HCN shells to apply effective concentrations of this gas. The negative experience of the French in the last war with HCN in artillery shells is not particularly encouraging.

C. Other Forms. Hand grenades, mines, "booby traps," etc. filled with HCN represent a possible effective but limited use of HCN. Thus used, HCN would be most effective in closed spaces where the high concentrations necessary could be quickly attained. Recent capture of a Japanese type grenade filled with HCN, with powdered copper as a stabilizer, proves that this Axis partner considers HCN effective for such use. However, it might also be contended that wherever such HCN grenades were used, high explosives or other substances would be equally, if not more, effective.

Summary

In summation, therefore, it seems that in the light of past experience, and of the physical and chemical difficulties to be overcome, HCN is not likely to be considered an effective war gas by the European Axis. This does not preclude the possibility that some new technical developments, unknown to the writers of this memorandum, may now make it possible to use HCN effectively. However,

large scale Axis use of HCN, even if it could now be applied satisfactorily, still seems unlikely. As a filling for artillery shells and aerial bombs, the lung-injurant type of gas like phosgene could in general achieve the results desired even more effectively.

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APPENDIX I

FORMS OF APPLICATION OF HCN IN WORLD WAR I

Country	Form of Application	Caliber	Weight of Chemical Filling (kg)	Composition of Chemical Filling
France	Artillery	75mm	0.45	)HCN 50%, AsCl3 50%)HCN 50%, AsCl3 30%, SnCl4 15 per cent) Chloroform 5%
	"	120mm.	1.1	HCN 46%, AsCl3 54%
	"	155mm.	2.6	HCN 50%, AsCl3 50%
"	Gas mine		3.75	HCN 50%, AsCl3 50%
"	Aerial bomb[13]	?	?	HCN 50%, AsCl3 30%, SnCl4 15% Chloroform 5%
"	Cloud gas[14] Attack	-	-	HCN additive to few chlorine attacks to increase toxicity
Russia	Artillery [15]	76mm.	0.80	HCN 50%, AsCl3 50%
England	Artillery [16]	127mm.	1.5	HCN 50%, AsCl3 50%

APPENDIX II

"LETHAL INDEX" COMPUTATIONS

Phosgene

For purposes of measuring relative toxicity of gases, Haber,[17] director of German chemical warfare in the last war, devised a formula which he called the "CT product", also called "mortality product,"[18] or "lethal index".[19] In Haber's formula, "C" represents the concentration of the gas in milligrams per cubic meter of air, and is multiplied by "T", which represents the time of exposure in minutes. The lower the lethal index, the more toxic is the substance.

By experiment, this "CT product," according to Haber, was found to have a constant value for the gases of the lung-injurant type, phosgene. Its value would therefore be independent of the concentration of the gas. Various lethal indices contained in literature are as follows:

400 - 500 - Haber, op.cit. for underfed animals in last war.

900 -1,000 -Flury, quoted in Hanslian, op. cit. p. 42, for revision of Haber's figures with better-fed animals.

3,000 -Wirth, quoted in Sartori, op.cit. p. 74.

8,000 -Prentiss, op.cit. p. 16; also average.

12,000 -Prentiss, op.cit. p. 13; curve, low concentration.

While these values are not consistent, the agreement is sufficient considering the wide range of concentrations covered - roughly 1 : 1,000 - from a few milligrams per cubic meter to a few thousand.

If the lethal index given by Prentiss (average 5,000) is assumed as correct, then the lethal dose of phosgene would be calculated as the product of the lethal index times the human breathing rate, say 8 liters of air per minute, and would therefore be about as follows:

5,000 mg. phosgene per cu. m. x minutes x 0.008 cu m. per minute =

40 milligrams phosgene

with upper and lower limits say of 10 to 100 milligrams in individual cases.

Hydrocyanic Acid

The "CT product" of HCN is known to vary with the concentration. According to Haber it is 1,000 to 4,000 the higher figure for the lower concentrations. Thus, taking a few examples:

3,000 mg. HCN per cu. m x ½ minute = 1000

which would give an instantaneously lethal effect at this high concentration.

or, 150 mg. HCN per cu.m x 30 minutes = 4,500[20]/

and 120 mg. HCN per cu. m. x 60 minutes = 7,200.

In these concentrations, which are medium range gas concentrations under field conditions, only a prolonged unprotected stay would be lethal.

Prentiss (p. 16) gives for HCN the lethal index of 2,000 = 200 mg. HCN per cu. m. x 10 minutes, and in Table IV (p. 282) another value:

4,500 = 150 mg. HCN per cu. m. x 30 minutes.

The concentrations of 120 to 150 milligrams HCN per cubic meter are already near the limit below which HCN ceases to be a poison gas at all. This limit is given in literature as 40 to 60 mg. HCN per cubic meter of air by Flury,[21], and as 30 mg. HCN per cubic meter by Sartori (op. cit. p. 187).

A single figure for the lethal dose of HCN (which was about 40 mg. for phosgene) cannot be given. In high concentrations, say around 3,000 mg. per cubic meter, it is probably from 10 to 20 milligrams, probably closer to 20. On the other hand, in low concentrations of 30 milligrams HCN per cubic meter of air - at which HCN is not considered poisonous - a quantity of:

30 mg. per cu. m. x 1 day or 1440 minutes x 0.008 cu. m. per minute = 30 x 11.5 = 300 to 350 mg. HCN

can be eliminated by the human system during the course of a day. This 300 to 350 milligrams of HCN which could be eliminated daily by the body is thus equivalent to 15 to 20 times the instantaneous lethal dose of 20 milligrams of HCN which would be lethal if breathed in the high concentration given above.

A note of caution must also be expressed as to the difficulty of applying values obtained in experimental data referring to different kinds of animals and transferring them to humans. In a classic experiment with HCN in England, under comparable conditions, a scientist placing a dog and himself for about 1½ minutes in a gas testing chamber filled with a concentration of one part in 2,000 of gas survived the experiment while the dog died.[22]

Post-war experimental data obtained in connection with the use of HCN for fumigation of ships, flour mills, etc. or with prison execution chambers are relatively less valuable for chemical warfare purposes since the former were concerned primarily with maximum concentrations which would readily be controlled. Chemical warfare is more properly interested in minimum concentrations approximating those that can reasonably be obtained under combat conditions.